Appendix C-4
Applying Lessons Learned from Land-Based Systems to Watercraft Safe Electrical Design

**IMPORTANT USER NOTE: This document was created in 2014 by the DoD Electrical Safety Working Group (ESWG) and is based on Codes and Standards in force in 2014. To use this document properly, the user must refer to the code in force at the date of use.*

INTRODUCTION

Electrocutions onboard watercraft is a hazard not only to electricians, but also to any other person who comes in contact with electrical energy during maintenance, painting, or other routine work activities. Electrical fires can cause vital equipment to malfunction or become disabled and disrupt operation or readiness.

Electricity is a hazard on watercraft and in shipyards. The electrical power onboard is made up of power generation equipment, an electrical distribution system, and the many utilizing devices. Electricity is used for the motor drive of many auxiliaries and also for deck machinery, lighting, ventilation and air conditioning equipment. "The potential for electrical shock hazards is great in shipbuilding and repair because workers stand on metal decks and often work in a wet environment. Work on or around energized electrical equipment can expose workers to electrocution, burns, or electrical shock" (Shipbuilders Council of America, 2008).

Design technologies are evolving for the control of electrical hazards that reduce the likelihood of injury including shock, arc flash, and damage and injuries which occur from electrical fires. Land-based electrical safe design technologies can reduce the risk of electrocutions and arc flash while enhancing productivity. Technologies currently exist that also limit the severity of electrical shock or arc flash and electrical fires. These technologies may be able to be used in watercraft and for future research. Each design technology should be considered during acquisition and concept.

DESIGN TECHNOLOGIES FOR REDUCING ELECTRICAL HAZARDS AND BUSINESS CASE

The following is a summary of design technologies which can be used and designed early on during the ship construction process to reduce the likelihood of electrocutions or serious personal injuries from an arc flash or explosion and electrical fires. Each technology has its disadvantages along with its advantages. An engineering analysis must be performed to determine the best type of equipment for the situation (Floyd, 2013).

1) **National Electrical Manufacturers Association (NEMA)/International Electrotechnical Commission (IEC) Approved Enclosures**: Enclosures provide protection from wet environments, corrosion, rust and other adverse environmental conditions. IEC standard 60529 defines Ingress Protection for enclosures containing equipment which can cause electrocutions. Refer to the appropriate sections of IEC 60529 for complete information regarding applications, features, and design tests for protection against inadvertent physical contact with energized conductors or circuit parts, protection against dust and splashing water, ice, and rust resistance. Table 1 and Figure 1(CableOrganizer.com) depict samples of enclosure ratings.

Table 1. Sample Enclosure Ratings

Rating	Protects Against
NEMA 1	Prevents accidental contact of worker with the enclosed equipment
NEMA 3R	Windblown dust, vertical rain, severe external corrosion
NEMA4X	Dust, watertight, splashing rain, hose directed water, ice, corrosion resistant
NEMA 7	Hazardous/explosion proof (classified) locations

Figure 1. Sample Enclosure Ratings

2) **Touch Proof Equipment:** Prevents individuals from contacting energized terminals directly or with equipment they are using. For dry conditions and free of dusts, specifying equipment meeting IEC 60529 IP2X ingress requirements is one method to ensure the equipment is touch proof.

3) **Arc Resistant Enclosures**: The severity of injury from an arc fault is significantly reduced because the high energy plasma and harmful gases are redirected away from the worker. It also can reduce damage to equipment in the surrounding environment. In Figure 2, arc resistant designs direct thermal energy away from where the worker would normally be positioned. In this example, the energy is directed out of the top of the switchgear.

Figure 2. Example Arc Resistant Enclosure

ANSI/IEEE C37.20.7- 2007, *IEEE Guide for Testing Metal Enclosed Switchgear Rated up to 38 kV for Internal Arcing Faults* defines switchgear arc resistance in two basic categories:

- ANSI type 1: Arc resistance from the front of gear only
- ANSI type 2: Arc resistance provided from the front, sides and rear (EATON Corp.)

4) **Ground Fault Detection Among Ungrounded Shipboard Systems**: Electrocution hazards are significantly reduced with ground fault detection and suppression capability (Bender, Inc.). The Navy is exploring "Innovative Approaches to Automatically Detect Ground Faults in Shipboard Control System" which could lead to advances in equipment and worker protection (NAVSEA, 2011).

5) **Design And Application Of Proper Coordination Of Relay And Circuit Breaker Setting**s: Proper operation and coordination of circuit breakers with an arc flash hazard analysis minimizes the likelihood for severe injury during an arc fault incident and provides equipment protection. It is often one of the easiest and least costly methods to reduce arc flash hazards. In Figure 3, time-current characteristic curve the tripping characteristics of a circuit breaker depicted on the left are selected to coordinate with the clearing characteristics of a fuse on the right. The selection of trip settings and fuse characteristic are design choices that impact arc flash energy exposures (Floyd, 2013).

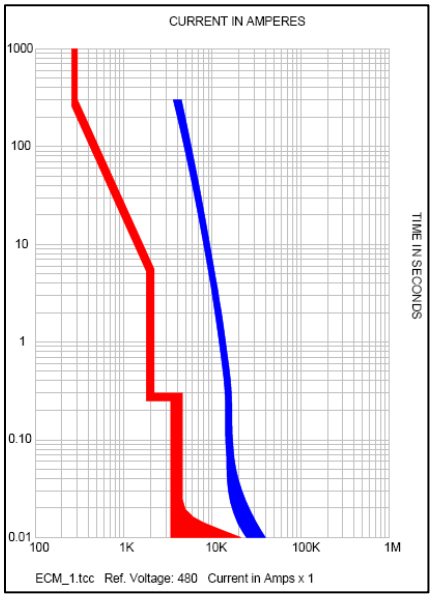

Figure 3. Coordination of Two Protective Devices in an Electric Power System

6) **Inspection View Ports**: Allow infrared and ultrasonic inspections of switchgear and other power distribution equipment without opening doors or removing covers that would expose persons to lethal energy. The likelihood for an arc flash is reduced and inspection ports prevent opening of cabinets with exposures to lethal electric current. Figure 4 shows infrared inspection viewpoints installed in industrial switchgear (Floyd, 2013). Figure 5 is a close up of an infrared viewpoint, and Figure 6 shows an ultrasound testing port (Floyd, 2013).

Figure 4. Infrared Inspection Viewports

Figure 5. Infrared Viewport - Closeup

Figure 6. Ultrasound Testing Port

7) **Smart Motor Control Centers:** Incorporate self-diagnostic capability and data communications to enable remote troubleshooting. This reduces the need for workers to be exposed to hazardous energy. The motor control center in Figure 7 has "smart" technology, including sensors and data highway that enables the technician to perform troubleshooting and adjust protective device settings without opening enclosure doors, avoiding exposure to unguarded energized components (Floyd, 2013). In Figure 8, the motor control center does not have "smart" technology. Troubleshooting must be done using chock and arc flash PPE to protect the workers from hazards form unguarded energized components (Floyd, 2013).

Figure 7. Motor Control Center – With "Smart" Technology

Figure 8. Motor Control Center – Without "Smart" Technology

8) **Arc Fault Circuit Interrupters (AFCI)**: AFCIs reduce the risk of electrical fire and protect property by detecting an unintended electrical arc and disconnecting the power before the arc causes a fire. The Consumer Product Safety Commission (CPSC) estimates that 50-75% of residential electrical fires could be prevented by use of AFCI technology, and estimates that total benefits exceed cost. Arc Fault Circuit Interrupter (AFCI) is available in outlets (Figure 9) and circuit breakers (Figure 10) (Floyd, 2013).

Figure 9. Outlets

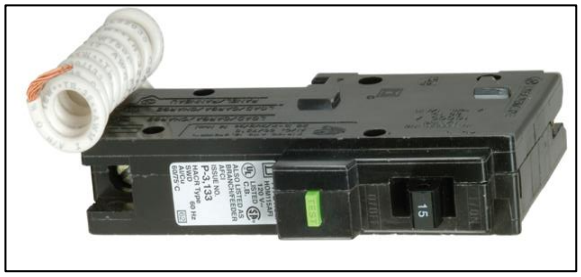

Figure 10. Circuit Breakers

9) **High Resistance Grounding:** High resistance grounding helps reduce the flow of unintended current or ground fault. The energy released from the ground fault can lead to process interruptions, equipment damage, as well as present a fire and explosion risk. A monitoring system sounds an alarm when a phase to ground fault occurs so that the system may be taken offline before the fault can become multi-phase.

10) **Covered Or Isolated Bus:** The purpose of a covered or isolated bus is to keep a single-phase fault from becoming a multiphase fault. Consequently, there is less available energy at the fault location.

11) **Current Limiting Fuses And Breakers:** By reducing the energy available for a fault, current limiting fuses and breakers reduce the probability and severity of an arc fault thus reducing both worker injuries and equipment damage. Figure 11 shows the time-current characteristics of a current limiting fuse. The amount of thermal incident energy in an arc flash event is proportional to the area under the curves. Current limiting fuses and circuit

breakers clear a fault with ¼ cycle. Non-current limiting fuses and circuit breakers can take longer (Floyd, 2013).

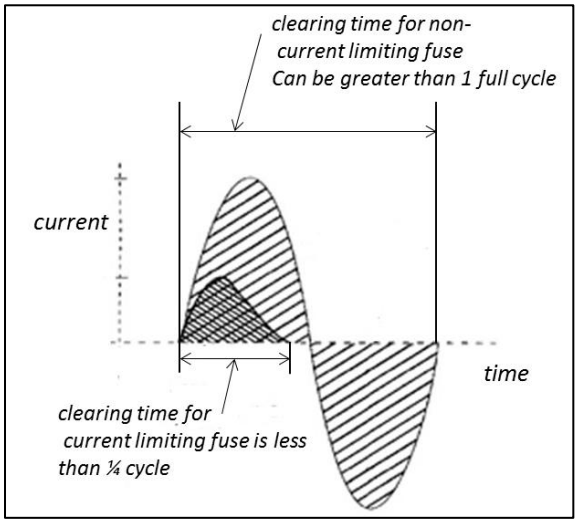

Figure 11. Time-Current Characteristics Of A Current Limiting Fuse.

12) **Remote Operation Of Equipment:** Remote operation of equipment separates electrical hazards from the worker. Examples include: remotely operating medium voltage switchgear, installing a motor control system away from the motor terminal box or motor control center (MCC), and use of "smart" MCCs which allows workers to troubleshoot remotely over the network. Figure 12 provides an example of remote racking and Figure 13 shows an example of remote switching.

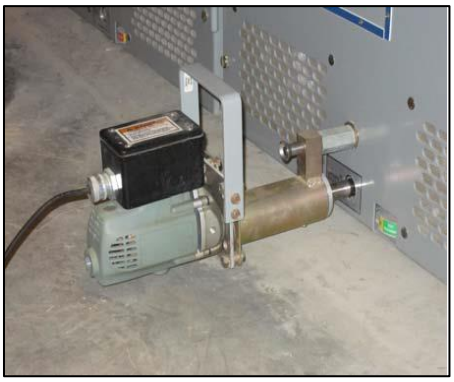

Figure 12. Remote Racking

Figure 13. Remote Switching

13) **Fully Withdrawable Motor Control Center:** Design ensures physical access to the inside of the unit can only be gained by removing the unit from the power bus (EATON). Withdrawable motor control centers provide the highest level of worker protection from arc flash during maintenance and with work involving possible contact with energized conductors or circuit parts. Figure 14 illustrates a fully withdrawable motor control center.

Figure 14. Fully Withdrawable Motor Control Center

14) **Arc Detection And Suppression Systems:** These systems reduce the risk of arc flash injury by detecting and responding to an arc flash condition. For example, arc suppression technology, NOsparc™ devices (Arc Suppression Technologies, 2013). Figure 15 illustrates how light detection can be used in addition to overcurrent detection. Overcurrent detection is the most common method to detect an arc flash event. This can enable a much faster tripping of the circuit breaker to limit arc flash incident energy (Floyd, 2013).

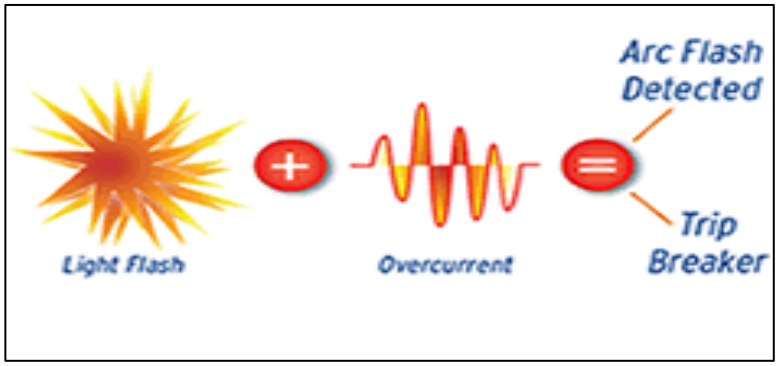

Figure 15. Overcurrent Detection

CONCLUSION

These technologies have been developed and proven for shore-based use and should be considered for adaptation for use where appropriate on watercraft.

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